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A NEW SIMPLE METHOD TO DERIVE SOME PORE-RELATED PROPERTIES OF LIMESTONE FROM THE WEIGHT OF 4-CM OVEN-DRIED LIMESTONE CUBES

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ABSTRACT
In a previous paper (Moh'd, 2002), the author has presented a technical note for estimating some pore-related properties of limestone from bulk density and water absorption data. The method includes measuring four parameters (W1, W2, W0 and W3) which are the weights of 4-cm cubes of limestone in different states of water absorption (oven-dried, soaked in water, vacuum-pumped and then soaked in air) to derive porosity, water saturation, water absorption (normal and vacuum pumped), and density (bulk, dry and grain). In the present work it was found that W2, W0 and W3 can be derived from W1 as revealed by 50 specimens of almost pure Jordanian limestone. This is important as in the new method there is no need for the use of a vacuum pump. This may be very useful both in the field and also in laboratories where the necessary equipment, or time, is unavailable. It is highly recommended to test more samples and to include both bituminous and non-bituminous limestones with primary and secondary porosity types (inter-granular, inter-crystalline, fracture and vuggy). Cubes with dimensions other than 4-cm and other specimen shapes such as cylinders (to simulate cores) are to be included.

INTRODUCTION
The porosity of carbonate rocks is very important with respect to their exploitation (in oil, mineral, and water exploration, as well as, in and as building and industrial materials). Microscopy (optical and electron) can provide qualitative information on the origin, distribution, and shape of pores. For a sufficiently accurate estimate of porosity, the use of other experimental techniques is required (Brown, 1981; Halley, 1978). Deriving the pore structure of carbonates using simple methods and its applications has been one important research interest of the author for the last 20 years which started during his PhD work on evaluating 12 Jordanian limestones as building stones (Moh'd, 1996; Moh'd et. al. 1996) and thereafter (Moh'd 2002; 2003; 2006a and b; 2007; 2008; 2009; 2012; 2015).

The present work is an extension of 2002 paper but emphasizes the inter-relationships between the different types of weight of cubic rock samples (W1, W2, W0 and W3). Accordingly, in order to obtain the data necessary to derive the pore-related properties, W1, W2, W0 and W3 have to be actually measured (as done in 2002 work) or derived (from W1 as emphasized) in the present work.

SAMPLES AND METHODS
Most of the building limestones in Jordan are quarried from different horizons of the Upper Cretaceous and Tertiary. These rocks, which are dominantly of limestone lithologies, cover most of Jordan. The stratigraphy of the late Cretaceous and early Tertiary in Jordan is shown in Table 1. Units with good potential as sources of building limestone are starred. The limestones are classified petrographically in Table 2 following Folk (1959; 1962) Dunham (1962), and Fookes and Higginbottom (1975) schemes.

Table 1. Stratigraphy of Cretaceous and early Tertiary rocks of Jordan

Series	Stage	Formation	Symbol	Description
	Eocene	Shallala/Ma'an*	SH/MNL	Chalk/Nummulitic limestone
Tertiary		Umm Rijam*	URC	Chalk,Chert, limestone

	Paleocene	Muwaqqar*	MCM	Chalk, marl, limestone concretions
	Maestrichtian	Al Hisa	AHP	Phosphorite, limestone, chert
Late	Sant./Camp.	Amman	ASL	Chert, limestone, dolomite
	Coniacian	Umm Ghudran	WG	Chalk
	Turonian	Wadi As Sir*	WSL	Limestone, dolomite
		Shuayb	S	Marl, nodular limestone
Cretaceous	Cenomanian	Hummar	H	Dolomite, limestone
		Fuhays	F	Marl, clayey
		Naur *	NL	Limestone, nodular, dolmite
Early Cretaceous		Kurnub Sandstone	KS	

Units with good potential as sources of building stone

It is important to note that in order to determine the specific gravity and water absorption, the ASTM standard (C 97-83) requires that the test specimens be immersed in water for 48 hours. However, as most of the water absorption takes place during the first few hours of immersion (Moh'd, 1996), the 24 hours immersion period used by BRE was considered sufficient to enable water absorption, density and effective porosity to be determined.

Table 2. Petrographic classification of Jordanian building limestones

Stone		Unit	Folk (1959, 1962)	Dunham (1962)	Fookes & Higginbottom (1975)
Ballas	B	WSL	Biomicrite	Mudstone-wackestone	Fine-grained limestone
Hallabat	HB	WSL	Biosparrudite	Packstone-grainstone	Bioclastic limestone
Hatem	HA	MCM	Micrite	Mudstone-wackestone	Carbonate siltstone (chalk)
Hayyan	HY	WSL	Biomicrite	Foss. wackestone	Bioclastic limestone
Izrit	IZ	MCM	Micrite	Mudstone-wackestone	Carbonate siltstone (chalk)
Jazeirah	MA	MNL	Biosparite	Packstone-grainstone	Bioclastic limestone
Karak	K	NL	Biosparite	Foss. packstone-grainstone	Bioclastic limestone
Saham	SA	PE	?	?	Conglomeratic limestone
Sahrawi	S	MCM	Microsparite	mudstone	Fine-grained limestone
Sat'h	MB	MNL	Biosparite	Packstone-grainstone	Bioclastic limestone
Tafih	T	AHP	Sparite	?	Crystalline limestone
Travertine	TR	PE	Sparite	?	Crystalline limestone
Yanabi	Y	WSL	Peloidal micrite	Wackestone (with packstone lenses)	Fine-grained limestone

PE: Post-Eocene ?: classes not known in Folk's and/or Dunham's classifications. Foss.: fossiliferous

The following definitions of terms are used:

Bulk density (g/cm^3): the weight of the oven-dried rock divided by its total volume (including pore-space), with volume being determined by normal immersion (without the use of a vacuum pump).

Dry density (g/cm^3): the weight of the oven-dried rock divided by its total volume, with volume being determined by immersion using a vacuum pump.

Grain density (g/cm^3): the weight of oven-dried rock divided by its volume (excluding pore-space).

Water absorption (%): the weight of water absorbed by the rock after 24 hours of immersion in water divided by its oven-dried weight expressed as a percentage of its oven-dried weight.

Apparent porosity (%): the percentage of volume of voids over the total volume of rock.

Effective porosity(%):indicates interconnected pores and is the product of water absorption and bulk density.

Saturation (%): the percentage of pore volume, which can be filled with water after immersion in water for 24 hours.

Formulae Used

The following measurements need to be made in order to determine the different pore-related properties

W_0: weight of oven-dried sample,
W_1: weight of sample soaked in water,
W_2: weight of sample (vacuum-pumped and then soaked) in air,
W_3: weight of normally immersed sample in air.

Assuming that the weight of the sample soaked in water (W_1) is equal to the weight of the sample normally immersed in water, then the following relationships exist:

$$\text{Porosity} = [(W_2 - W_0) / (W_2 - W_1)] \times 100 \quad (1)$$

$$\text{Normal water absorption} = [(W_3 - W_0) / (W_0)] \times 100 \quad (2)$$

$$\text{Vacuum-pumped water absorption} = [(W_2 - W_0) / (W_0)] \times 100 \quad (3)$$

$$\text{Bulk density} = W_0 / (W_3 - W_1) \quad (4)$$

$$\text{Dry density} = W_0 / (W_2 - W_1) \quad (5)$$

$$\text{Grain density} = W_0 / (W_0 - W_1) \quad (6)$$

$$\text{Saturation} = (W_3 - W_0) / (W_2 - W_0) \quad (7)$$

It is important to remember that the total volume of rock measured using a vacuum pump (Brown, 1981; RILEM, 1980; Price, 1975; Ross and Butlin, 1989) is higher than that measured by normal immersion, because air filling the pore space is removed in the former and hence water has better access to the pores. Consequently, bulk density, as prescribed in the ASTM standard (C 97-83), is higher than dry density.

RESULTS

The results of the present work are shown in Table 3. A correlation matrix between the different weights (Table 4), shows very high to perfect correlation coefficients. This is further evidenced in Figures 1 through 3, with clear positive linear relationships.

Table 3 Results of the present work.

	W1 g	W2 g	W0 g	W3 g	Porosity %	Saturation fraction	Water Abs %	Bulk Density g/cm^3	Grain Density g/cm^3
HM7	101.82	179.26	161.31	174.98	23.18	0.76	8.47	2.08	2.71
HM8	95.66	168.77	151.69	164.51	23.36	0.75	8.45	2.07	2.71
HM9	88.69	157.03	140.69	153.19	23.91	0.76	8.88	2.06	2.71
HM10	86.07	149.88	136.56	146.94	20.87	0.78	7.60	2.14	2.70
HM11	89.8	157.55	142.45	154.11	22.29	0.77	8.19	2.10	2.71
HM12	85.97	151.51	136.37	148.1	23.10	0.77	8.60	2.08	2.71
MA7	116.15	186.92	184.01	185.2	4.11	0.41	0.65	2.60	2.71
MA8	105.29	170.37	166.77	168.37	5.53	0.44	0.96	2.56	2.71
MA9	100.49	161.77	159.17	160.11	4.24	0.36	0.59	2.60	2.71
MA10	121.79	196.45	192.97	194.68	4.66	0.49	0.89	2.58	2.71
MA11	111.6	180.04	176.82	178.07	4.70	0.39	0.71	2.58	2.71
MA12	119.84	193.18	189.86	191.23	4.53	0.41	0.72	2.59	2.71
Y7	137.83	219.51	218.31	219.26	1.47	0.79	0.44	2.67	2.71
Y8	124.54	198.53	197.3	198.33	1.66	0.84	0.52	2.67	2.71
Y9	144.38	229.93	228.65	229.67	1.50	0.80	0.45	2.67	2.71
Y10	144.35	229.91	228.61	229.65	1.52	0.80	0.45	2.67	2.71
IZ7	90.34	162.69	144.33	160.13	25.38	0.86	10.95	1.99	2.67

IZ8	88.74	161.07	141.91	158.32	26.49	0.86	11.56	1.96	2.67
IZ9	85.27	155.44	135.99	152.31	27.72	0.84	12.00	1.94	2.68
IZ10	86.82	157.71	138.35	154.68	27.31	0.84	11.80	1.95	2.68
T7	94.61	161.44	149.45	156.35	17.94	0.58	4.62	2.24	2.73
T8	104.48	177.27	165.26	171.75	16.50	0.54	3.93	2.27	2.72
T9	105.49	179.28	166.86	173.71	16.83	0.55	4.11	2.26	2.72
T10	103.87	177.16	164.3	171.49	17.55	0.56	4.38	2.24	2.72
MB7	114.11	183.04	181.3	182.11	2.52	0.47	0.45	2.63	2.70
MB8	110.17	176.78	174.95	175.76	2.75	0.44	0.46	2.63	2.70
MB9	116.75	187.69	185.04	185.98	3.74	0.35	0.51	2.61	2.71
MB10	118.16	189.64	188.23	188.93	1.97	0.50	0.37	2.63	2.69
HY7	128.99	210.66	204.45	209.23	7.60	0.77	2.34	2.50	2.71
HY8	121.54	199.54	192.56	198.02	8.95	0.78	2.84	2.47	2.71
HY9	124.47	203.86	197.24	202.35	8.34	0.77	2.59	2.48	2.71
HY10	135.97	220.28	215.42	219.08	5.76	0.75	1.70	2.56	2.71
B7	122.83	195.72	194.68	195.48	1.43	0.77	0.41	2.67	2.71
B8	113.81	181.32	180.31	181.11	1.50	0.79	0.44	2.67	2.71
B9	112.32	179.1	177.82	178.78	1.92	0.75	0.54	2.66	2.71
B10	117.52	187.35	186.15	187.09	1.72	0.78	0.50	2.67	2.71
TR2	108.82	173.57	172.7	173.17	1.34	0.54	0.27	2.67	2.70
TR5	113.05	181.06	179.74	180.48	1.94	0.56	0.41	2.64	2.70
TR6	114	181.43	180.76	181.19	0.99	0.64	0.24	2.68	2.71
K7	64.55	103.33	102.57	103.13	1.96	0.74	0.55	2.64	2.70
K8	60.07	96.22	95.45	96	2.13	0.71	0.58	2.64	2.70
K9	68.1	108.93	108.2	108.75	1.79	0.75	0.51	2.65	2.70
K10	68.68	109.68	109.33	109.58	0.85	0.71	0.23	2.67	2.69
S7	105.55	174.24	167.19	170.67	10.26	0.49	2.08	2.43	2.71
S8	96.44	160.73	152.86	157.1	12.24	0.54	2.77	2.38	2.71
S9	95.45	159.7	151.3	156.27	13.07	0.59	3.28	2.35	2.71
S10	96.64	162.18	153.19	158.59	13.72	0.60	3.53	2.34	2.71
HB7	101.64	176.07	161.07	170.73	20.15	0.64	6.00	2.16	2.71
HB8	103.32	179.29	163.59	174.39	20.67	0.69	6.60	2.15	2.71
HB9	107.02	182.34	169.76	177.84	16.70	0.64	4.76	2.25	2.71
HB10	113.2	190.7	179.6	186.14	14.32	0.59	3.64	2.32	2.70

Table 4 Correlation matrix between the measured weight parameters.

	W1	W2	W0	W3
W1	1.00			
W2	0.98	1.00		
W0	1.00	0.98	1.00	
W3	0.99	1.00	0.99	1.00

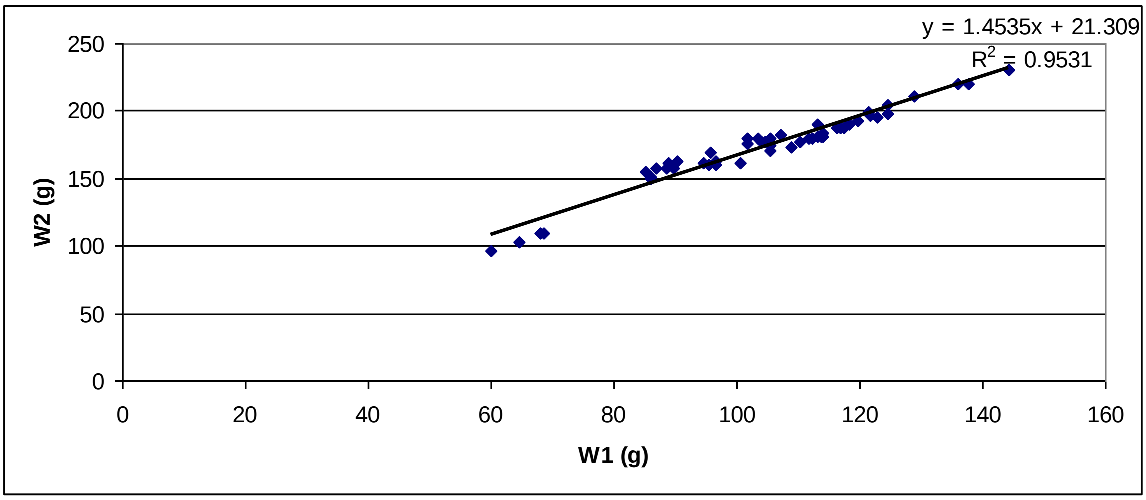

Figure 1Very strong linear positive relation between W1 and W2.

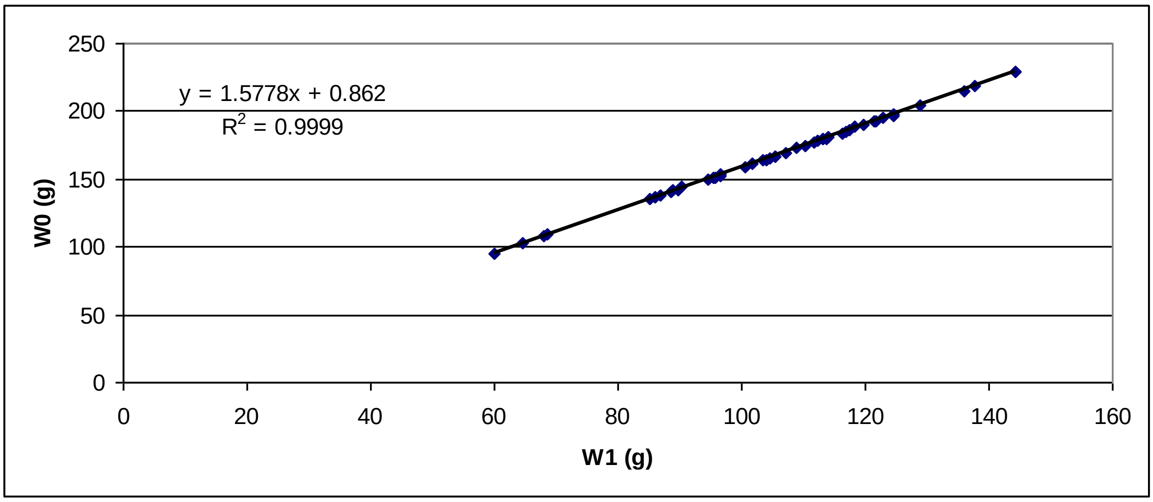

Figure 2Perfect positive linear relation between W1 and W0.

Recommendations

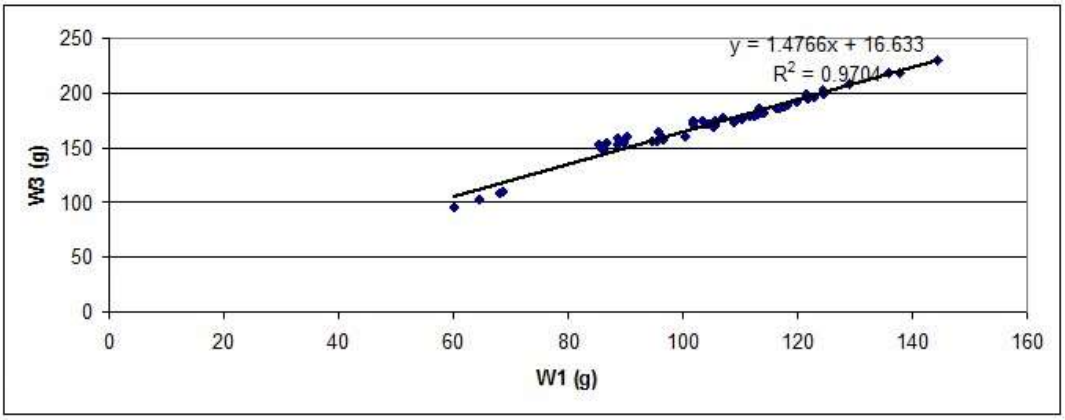

Figure 3Very strong positive linear relation between W1 and W3.

CONCLUSIONS AND RECOMENDATIOS FOR FURTHER WORK

From W1 (weight of sample soaked in water), and using the three equations in figures 1 through 3, W0, W2 and W3 can be derived. Once the weights are known they can be used in equations 1 through 7, to estimate porosity, water absorption (normal and vacuum-pumped), density (bulk, dry, grain) and water saturation. Using W0, weight of oven-dried sample, instead of W1 to derive the other weights may save testing time as drying of samples in the oven takes very short time (around one hour) compared to waiting for 24 hours to allow the samples to soak in water.

To apply this method, samples of rock has to be cut in the form of 4-cm cubes, oven dried in the oven at 105 C for one hour or until they reach constant weight, then using the equations in Figures 4 through 6 to derive W1, W2 and W3 from W0 and finally insert the results in equations 1 through 7 to derive the pore related properties (porosity, water absorption, density and water saturation).

Time saving is an advantage of the new proposed method as there is no need to wait 24 hours for soaking to occur. Moreover, vacuum pumping of samples may not be possible simply because the necessary equipment is unavailable. The new method curtails the need for vacuum pumping as the vacuum-pumped weight can be estimated from the derived equations (see figures 1 -6).

The data presented in this paper cover relatively pure limestones, which have very small amounts of clay minerals, silica, and dolomite present. The results of this work should not be generalized to apply to impure limestones and other lithologies without further study. Carrying out similar work on impure limestone lithologies (marl, marly limestones, dolomite, dolomitic limestones, and sandy limestones) and other rock types is highly recommended. A prerequisite for using immersion methods is that the tested rock should not swell appreciably or disintegrate when oven-dried and immersed in water.

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